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LHC Prospects on Higgs boson searches

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Abstract

The search for the Higgs boson and physics beyond the Standard Model will be the most important tasks of the two multi-purpose experiments ATLAS and CMS, which will be placed inside the LHC 14 TeV proton-proton accelerator. The most recent studies, which have been developed with detailed simulations of the detector geometry and response, has pointed out that the LHC detectors have the possibility to cover the whole Standard Model Higgs boson mass spectrum and most of the MSSM parameter space.

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1 Introduction

The origin of the mass of elementary particles, whose electroweak and strong interactions are described by the Standard Model theory (SM), is thought to be the result of the electroweak symmetry breaking mechanism, which predicts the existence of a new particle, the Higgs boson [1]. Experimental observations have confirmed the validity of the Standard Model, but the Higgs boson itself has never been detected. Supersymmetry (SUSY), which relates masses and couplings of scalars and fermions, provides an elegant solution to the *hierarchy problem* of the SM [2]. In the minimal supersymmetric extension of the SM (MSSM) [3], each of the known fundamental particles have a super-partner with spin differing by $\frac{1}{2}$ and there are five five Higgs scalar mass eigenstates: one CP-odd neutral scalar A, two charged scalars $\mathrm{H}^{\pm}$ and two CP-even neutral scalars h and H (with masses $m_{\mathrm{h}} < m_{\mathrm{H}}$). At tree level the five Higgs bosons masses can be computed in terms of only two parameters, typically chosen to be $\tan\beta$, the ratio between Higgs scalar doublets vacuum expectations values, and m_{A}, the mass of the pseudoscalar neutral Higgs boson A.

A very powerful accelerator, the Large Hadron Collider (LHC), is being constructed at the European Laboratory of Particle Physics (CERN) in Geneva, Switzerland, so as to allow a Higgs boson discovery and to search for new physics phenomena up to the TeV energy scale [4]. Two oppositely directed proton beams will be accelerated to a total centre-of-mass energy of 14 TeV and will collide every 25 ns in correspondence of the experimental areas, where particle detectors will be placed. Two of the approved LHC experiments are "A Toroidal LHC ApparatuS" ATLAS [5] and the "Compact Muon Solenoid" CMS [6]. Both experiments will start data taking during the year 2008, after the LHC machine pilot run scheduled in the Autumn 2007.

2 Standard Model Higgs boson search

The Standard Model is extremely predictive in the Higgs sector, because all couplings, decay widths and production cross sections are given in terms of the unknown Higgs boson mass m_{H}, being the other parameters experimentally measured. There is not a single production mechanism or decay channel that dominates the whole accessible mass range from 100 GeV$/c^2$ to 1 TeV$/c^2$ at LHC. Instead several scenarios open up depending on the Higgs boson mass m_{H}.

The statistical significance for the Standard Model Higgs boson signal observation with 30 fb^{-1} integrated luminosity is shown in Fig. 1 for m_{H} ranging between 80 GeV$/c^2$ and 1 TeV$/c^2$, for ATLAS [7] and CMS [8] experiments. Combining the results for all the channels, almost all the allowed mass range not yet experimentally excluded should be explored during the first year at LHC. After two years about 30 fb^{-1} integrated luminosity per experiment will be collected and a 7σ signal significance should be reached over the whole mass spectrum, covered by more than one channel.

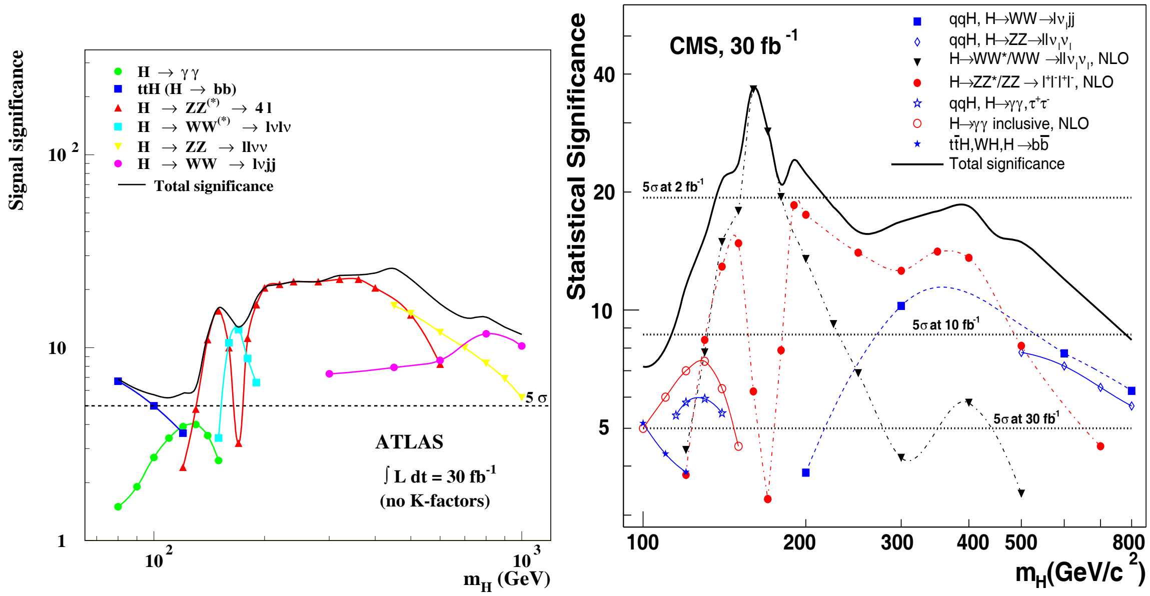
In the lower mass region, a 2σ significance should be reached during the first year of LHC in different channels: the $\mathrm{t\bar{t}H}$ associated production followed by top quarks decays $\mathrm{t}\to\mathrm{bW}(\to\ell\nu)$ ($\ell = \mathrm{e}, \mu$) and $\mathrm{t}\to\mathrm{bW}(\to\mathrm{q\bar{q}'})$ [9], the decay $\mathrm{H}\to\gamma\gamma$ [10] and the vector boson fusion (VBF) process $\mathrm{qq}\to\mathrm{qqVV}\to\mathrm{qqH}$ ($\mathrm{V}=\mathrm{W}$ or Z) [11]. The observation of all these channels is very important to extract a convincing signal during the first years of LHC operation. It is likewise important to reduce the uncertainty on background knowledge to less than 10%; this precision could be already reached during the first years of data taking.

At the opening of the ZZ decay channel, the fully leptonic decay $\mathrm{H}\to\mathrm{ZZ}^{(*)}\to 4\ell$ ($\ell = \mathrm{e}, \mu$) has the cleanest experimental signature, for this reason it is called the "golden" channel at LHC. The luminosity required for a 5σ discovery is less than 30 fb^{-1} and corresponds to about two years of data taking at low luminosity [12]. If $m_{\mathrm{H}} < 2m_{\mathrm{Z}}$ only one Z can be reconstructed. As a result higher luminosity is needed to observe the signal.

3 MSSM Higgs boson search

3.1 Neutral Higgs bosons h, H and A

The dominant production mechanism in the phenomenologically relevant Higgs mass ranges for small and moderate values of $\tan\beta$ is the gluon-gluon fusion process. At large $\tan\beta$, the associated production involving a $\mathrm{b\bar{b}}$ pair is enhanced by the large Yukawa couplings to down-type quarks. The main decays are into $\mathrm{b\bar{b}}$ (about 90%) and $\tau^+\tau^-$ pairs (about 10%). A clean signature can be extracted by the $\mathrm{h/H/A}\to\mu^+\mu^-$ decay channel, although the branching ratio into $\mu^+\mu^-$ is 3×10^{-4} over all the mass range for $\tan\beta=30$. Nevertheless there are some factors that can provide an observable rate and make this channel appealing: at large $\tan\beta$ rates are enhanced through associated $\mathrm{b\bar{b}h/H/A}$ production and, to some extent, the reduction in signal rate with respect to the $\tau^+\tau^-$ channel



(a) (b)

Figure 1: Expected sensitivity for the observation of the Standard Model Higgs boson signal as a function of the mass m_{H} with ATLAS (a) and CMS (b) with 30 fb^{-1} integrated luminosity.

is compensated by the much better identification efficiency achieved in the $\mu^+\mu^-$ channel. If the neutral Higgs boson mass is not too close to the Z mass, with 30 fb^{-1} of integrated luminosity the signal significance is greater than 5σ and thus a discovery for $\tan\beta = 30$ is possible [13].

3.2 Charged Higgs Bosons

The search for the MSSM charged Higgs boson $\mathrm{H}^\pm$ is performed in two different ways depending on the mass $m_{\mathrm{H}^\pm}$ and the dominant decay channels. The light charged Higgs boson is searched in the $\mathrm{H}^\pm \to \tau\nu_\tau$ decay channel, whose branching ratio is about 100%. It is produced by top quark decays $\mathrm{t} \to \mathrm{bH}^\pm$. The background with an isolated lepton from the accompanying W decay in $\mathrm{t} \to \mathrm{bW}^\pm$ is suppressed by searching for channels with a single τ jet or two τ jets in the final state. A 5σ significance can be reached [14] with 30 fb^{-1} if $m_{\mathrm{H}^\pm} < 100$ GeV$/c^2$.

The heavy charged Higgs boson is searched for exploiting the main decay channel $\mathrm{H}^\pm \to \mathrm{tb}$ in the associated production process $\mathrm{gg} \to \mathrm{btH}^\pm$, even with low signal-to-background ratios due to the $\mathrm{t\bar{t}}$ multi-jet background. Also the $\mathrm{H}^\pm \to \tau\nu_\tau$ and $\mathrm{H}^\pm \to \mathrm{Wh}$ decays can be studied. The $\mathrm{H}^\pm \to \tau\nu_\tau$ is particularly interesting when hadronic τ decays are required, because the $\mathrm{t\bar{t}}$ and tW backgrounds can be suppressed exploiting the different helicity correlations in the $\mathrm{H}^\pm \to \tau\nu_\tau$ and $\mathrm{W}^\pm \to \tau\nu_\tau$ decays. The $\mathrm{H}^\pm \to \mu\nu_\mu$ decay can be efficiently extracted with integrated luminosity exceeding 100 fb^{-1}.

References

[1] P.W. Higgs, *Phys. Lett.*, **12** (1964) 132-133, *"Broken Symmetries and the Masses of Gauge Bosons"*; P.W. Higgs, *Phys. Rev. Lett.*, **13** (1964) 508-509, *"Broken Symmetries and the Masses of Gauge Bosons"*; P.W. Higgs, *Phys. Rev.*, **145** (1966) 1156-1163, *"Spontaneous Symmetries Breakdown Without Massless Bosons"*;
F. Englert and R. Brout, *Phys. Rev. Lett.*, **13** (1964) 321-322, *"Broken Symmetry and the Mass of Gauge Vector Mesons"*;
G.S. Guralnik, C.R. Hagen and T.W.B. Kibble, *Phys. Rev. Lett.*, **13** (1964) 585-587, *"Global Conservation Laws and Massless Particles"*.

[2] P. Fayet, *Phys. Lett.*, **B64** (1976) 159, *"Supersymmetry and Weak, Electromagnetic and Strong Interactions"*, P. Fayet, *Phys. Lett.*, **B69** (1977) 489, *"Spontaneously Broken Supersymmetric Theories of Weak, Electromagnetic and Strong Interactions"*;

G. R. Farrar and P. Fayet, *Phys. Lett.*, **B76** (1978) 575-579, *"Phenomenology of the Production, Decay, and Detection of New Hadronic States Associated with Supersymmetry"*.

[3] H. P. Nilles , *Phys. Rept.*, **110** (1984) 1, *"Supersymmetry, Supergravity and Particle Physics"*;
H. E. Haber , *Phys. Rept.*, **117** (1985) 75, *"The Search for Supersymmetry: Probing Physics Beyond the Standard Model"*;
L. E. Ibanez, G. G. Ross, *Phys. Lett.*, **B110** (1982) 215-220, *"$SU(2)_L \times U(1)$ Symmetry Breaking as a Radiative Effect of Supersymmetry Breaking in GUTs"*;
S. Dawson, hep-ph 9712464, *"The MSSM and why it Works"*.

[4] The LHC Study Group, CERN/AC/95-05 (1995), *"The Large Hadron Collider Conceptual Design Report"*.

[5] ATLAS Collaboration, *"ATLAS: A Toroidal LHC ApparatuS Technical Proposal"*, CERN/LHCC-94-43, LHCC/P2.

[6] CMS Collaboration, *"The Compact Muon Solenoid Technical Proposal"*, CERN/LHCC 94-38, LHCC/P1, 15 December 1994.

[7] ATLAS Collaboration, ATLAS TDR 15, CERN/LHCC 99-15, *"Atlas Detector and Physics Performance - Technical Design Report Vol. II"*.

[8] S. Abdullin *et al.*, CMS Note 2003/033, *"Summary of the CMS Potential for the Higgs Boson Discovery"*.

[9] J. Camin and M. Schumacher, ATL-PHYS-2003-024, *"The ATLAS discovery potential for the channel $t\bar{t}H$, $H \rightarrow b\bar{b}$"*.

[10] ATLAS Collaboration, CERN/LHCC 96-40 ATLAS TDR 1, , *"Calorimeter Performance Technical Design Report"*; CERN/LHCC 96-41 ATLAS TDR 2, *"Liquid Argon Calorimeter Technical Design Report"*.

[11] S. Asai *et al.*, arXiv:hep-ph/0402254, *"Prospects for the search for a standard model Higgs boson in ATLAS using vector boson fusion"*.

[12] M. Sani, *Czech. J. Phys.* **55** (2005) B101, *"Search for the standard model Higgs boson in the four-muon final state with CMS"*.

[13] S. Marcellini and G. Masetti, CMS NOTE in preparation, *"Search for the MSSM Neutral Higgs Boson in the Two Muons Channel"*.

[14] R. Kinnunen, CMS NOTE-2006/100, *"Search for the heavy charged MSSM Higgs bosons with the $\mathrm{H}^+ \rightarrow \tau^+\nu$ decay in fully hadronic final state"*;
M. Baarmand, M. Hashemi and A. Nikitenko, CMS NOTE-2006/056, *"Light Charged Higgs Discovery Potential of CMS in the $\mathrm{H}^+ \rightarrow \tau\nu$ Decay with Single Lepton Trigger"*.